Fourth International Conference on the History of Transport, Traffic and Mobility,
Paris and Marne-la-Vallée, France 28 September – 1 October 2006

Why economical driving of motor vehicles is always prohibited

The technology of roads and means of transport in interaction with the public investments in traffic from 1890-2006[1]

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It has always been possible to build motor vehicles that are larger and faster - and therefore more economical - than the authorities will allow. It appears to be a paradox, but the considerations of the conditions of roads and bridges have been weighted more heavily. The carrying capacity of bridges and roads has natural limitations, and road administrators want to minimize the wear and tear: A large truck tears 70,000 times more than a light single-passenger car. The infrastructure has thus always been behind the technological development of the motor vehicles.

This paper is based on larger revisions of the legislation and traffic regulations. It will show, on one side, the interaction between the possibilities of the motor vehicles and the demand for road transport and, on the other side, the conditions of the infrastructure and the general investments in transport.

The examples are from Denmark. Denmark is a European industrialised country and in many ways representative for this type, but in spite of this it has not been dominated by heavy transport to and from large-scale industry; moreover, it has had advantages through easy access to good harbours.

Roads for horses

One day in the autumn in 1862, a cargo boat entered a harbour in the northern part of Denmark. Its cargo was a new kind of vehicle. With much attention, the first steam-driven vehicle for roads would be driven on a fixed timetable. The authorities were cautious, and they wanted to make demands, including the claim that the vehicle had to be approved. One reason was public security: for instance, the dangerous steam boiler. To drive the more than 10-ton vehicle, the owner should be responsible to reinforce all the bridges on the road where he would drive. The authorities did not make any claims for the reinforcement of the roads, though they probably should have done so. At least the developer should have thought about it: He soon realised that the "steam elephant" got stuck in the soaked roads when it rained. The experiment had to be ended, and the developer lost almost all of his money.

Except for this little intermezzo, horses had the roads to themselves. During the 1800s, the railway had taken over long-distance transportation together with the steamed-powered boats. Only the regional transportation went by horse-driven carriages.

Driving with horse carriages had some very natural limitations: the horsepower. Normally a vehicle had only one or two horses. Few were driven by four-in-hand, and only as an exception were more horses involved, such as when a stone road roller weighing 4-5 tons at road construction would be driven by up to 10 horses.

The weight of the largest horse carriages was between 3 and 4 tons. This weight was, however, dependent on the condition of the road. If it was not optimal but had small hills – as most roads do – the horses could not manage as much weight. Conversely, they could manage more if the roads were optimal: In the 1930s, with the good roads the heaviest carriages had a weight of almost five tons, where the carriage alone had a weight on 1,3 tons. To this came the weight of the horses on each 900 kg.

The roads could normally handle transportation. They were continuously being improved, and after the introduction of the new technology for making roads, the macadam process, named after the Scottish inventor MacAdam, the roads were normally fine. Roads near harbours and similar roads with much transportation were paved with stones, first with cobblestones and later on with the new and very smooth sett paving.

The road-destroying motor vehicles

Around the year 1900, the automobiles became so great in number that they became fixtures on the roads. Although there were only a few hundred – not very many by today's measure – they were a phenomenon that had to be taken into consideration.

This situation was serious because they couldn't without any fuss drive on the same roads as the horse carriages. Their relatively high speed together with their deafening noise scared the naturally nervous horses. Worse, their speed caused the rubber wheels to suck the sand away from the macadam road cover. In short time a road could be totally destroyed by the motor vehicles.

This meant that society had to make regulations for the use of roads. Where the rules for horse travel were very sparse, there soon appeared a long list of demands for the arrangements of the vehicle and the driver, too. The destroying speed also had to be reduced through drastic limitations.

The light, private vehicles for personal transport had their own problems, but in this paper we will only look at the circumstances of the heavy vehicles.

With the fast technological development at that time, a vehicle was no longer restricted by a tractive force on one, two, or four horses. Soon reliable motors could be made with more than 10 HP, and in theory vehicles could be built for cargo weighing more than 100 tons. The authorities soon became aware of the problems with the heavy vehicles, and they set up restricting rules. According to one of the rules, the trucks had to have "rubberbandage" on the wheels that naturally would reduce the noise from driving on the stone-paved roads in the towns.

A more far-reaching rule was that cars were only allowed to drive on secondary roads if they had special permission from the Ministry of Justice through an application by the local authorities. Usually they only allowed very light vehicles.

In 1913, the supporters of motorcars became so strong that they could force some dispensations through a revision of a law. According to the new rules, small cars under a certain weight limit were allowed to drive on the secondary roads (and Danish car producers started to build a special "secondary road car"). It was still the local authorities that, through the police regulations, decided on possible reductions in driving.

After some years with restrictions caused by the First World War, the traffic became normal again, and it often was carried out by larger vehicles. For instance, many heavy trucks were imported that during the war had been driving for the allied power in France. Where there had been only around 15.000 trucks before the war in France, an account told that there were 180.000 vehicles when the war ended.

Those far heavier trucks brought a requirement of road protection. In a new law from 1921, restrictions were imposed on the self-weight of the vehicles, a maximum of 4 tons. The total weight was similar, 8 tons maximum.

Trucks had to pay for the wear and tear

At that time no one had had experience for many years with the wear and tear on the roads. It was easily understood that fast driving by the motorcars pulled the sand away, and therefore it was necessary to counteract this demolition and the simultaneous dust nuisance by giving the roads a surface treatment: for instance, by ejection of tar.

The wear and tear by the heavy trucks was another kind of damage. They seldom drove so fast that there was a dust nuisance, but they destroyed the road by breaking the surface and created potholesit.

It became evident that the roads had be improved so the potential of the new vehicles could be exploited. In 1915, a

This American truck of the Mack brand came in a large number to Europe for the allied forces in France. Hereby came a lot of heavy trucks in use in the civil area.
This truck is build 1918 and drove at a factory until late 1960's. Its 4 cylinder motor could deliver 74 HP, the vehicle had a weight on 5.300 kg and could handle a load on more than 5.000 kg.
The vehicle is now restored.

new road tax was introduced where the income went almost totally to building and repairing roads. It was a fine and reasonable principle in which the vehicles themselves paid for the wear and tear, and for the first several years the state did not led its hands on the increasing tax income that many times.

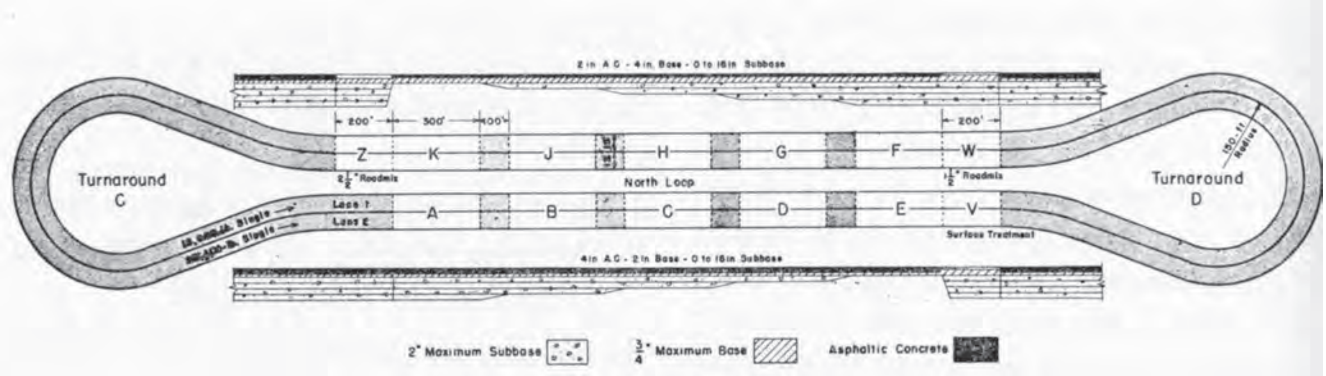
Knowledge of wear and tear and carrying capacity

The road authorities and politicians also did not know how much the vehicles wore on the roads. One very heavy truck could go through the surface of a road, but many lighter trucks had to drive on a road for, for instance, half a year before the road was demolished. This final accumulated wear and tear was the big question for the road authorities. It was the most important question when the authorities met, but they did not get any single-valued answer. Road construction was no exact science, and the fundamental research was first slow to be developed.

A kind of rule-of-thumb was developed about the tearing from vehicles when the road authorities calculated how long a special road construction could exist before repairing or what kind of coating was the best for a road with a certain or calculated traffic: It could be stipulated through extrapolation with the help of a traffic census.

The formula became *tons per meter per day*. A representative sample of vehicles was weighted, and from this an average was found. The numbers of tons could now be stipulated by counting the numbers of vehicles of every kind. This fluctuated only a little over time in the 1920s, where, for instance, the weight of a horse carriage in 1929 was 2,39 tons, an automobile with pneumatic tires (= a personal car, vans, and light trucks) 1,55 tons, while a motorcar with a solid or a half-solid tire had a weight of 5,78 tons (= trucks).

In the formula the broadness of the road was included. The tear would be different on a road depending on whether the traffic was spread over a broad range or all the vehicles drove in the same track.



The WASHOO experiments in 1953-1954 were some of the milestones in the scientific development of roads knowledge. On two roads like the one on the image several kinds of pavement were investigated under controlled conditions.

The counting could by this theory be used to plan road building. After inspiration from Sweden, the raising numbers of vehicles in the future could ultimately be doubled. So the most trafficked roads – those with at least 200 vehicles on a day, equal with 75 tons per meter of the road – should be extended. For example, in 1925 a traffic count was performed in Århus, the second largest town in Denmark, that showed that the road with the most traffic had a total transportation of 2.300 tons in eight hours.

The formula was rather unscientific, and later on it proved to be totally wrong. In spite of the fact that it was used to make serious decisions about, for instance, dimensioning, the engineers at the road, authorities knew that the formula was wrong. They knew that a heavy truck or a bus weighing 8 tons tore the road much more than eight passenger cars weighing 1 ton each. Thus came the police regulations, the laws about traffic, and the dispensation practice for the local road administration managed after the principle that the heaviest vehicles should be kept away from the weakest roads. Similarly, speed limits were imposed so the largest trucks would drive slowly, and the tax system was introduced so the owners of the heaviest vehicles relatively paid much more.

It was common sense that ruled at that time.

The development of research-based knowledge

The weakest part of the chain determines the strength of the chain. The same was true for a road system where the flimsiest bridge or the poorest road gave the limits for how heavy a vehicle could be.

For bridges there was rather good knowledge early on. The engineers had a long tradition for dimensioning bridges for railways, and with this knowledge the carrying capacity could rather easily be calculated. When the new traffic rules appeared in the 1920's allowing heavier vehicles, it was at the same time a goal for what a bridge should handle. Therefore, most local authorities had to make their bridges stronger.

In contrast, however, the roads were more difficult to handle. Their placement, the underground, the water level, the type of cover, and the thickness could vary in numberless combinations. For acquiring more knowledge many different practical experiments were started to measure the wear and tear.

An epochal experiment was establishing a so-called pilot road at Roskildevej, the largest road out of Copenhagen. The large highway was simply in a distance of 250 meters made particularly broad so there could be a lane for each kind of traffic: horse driven vehicles had one, motor cars with massive or half-massive tires had another, and cars with pneumatic tires had another. Now it was only a matter of counting the numbers of the vehicles in each lane (it soon became possible to make it automatic by electronic devices). Hereby it was possible to measure the tearing from each kind of vehicle.

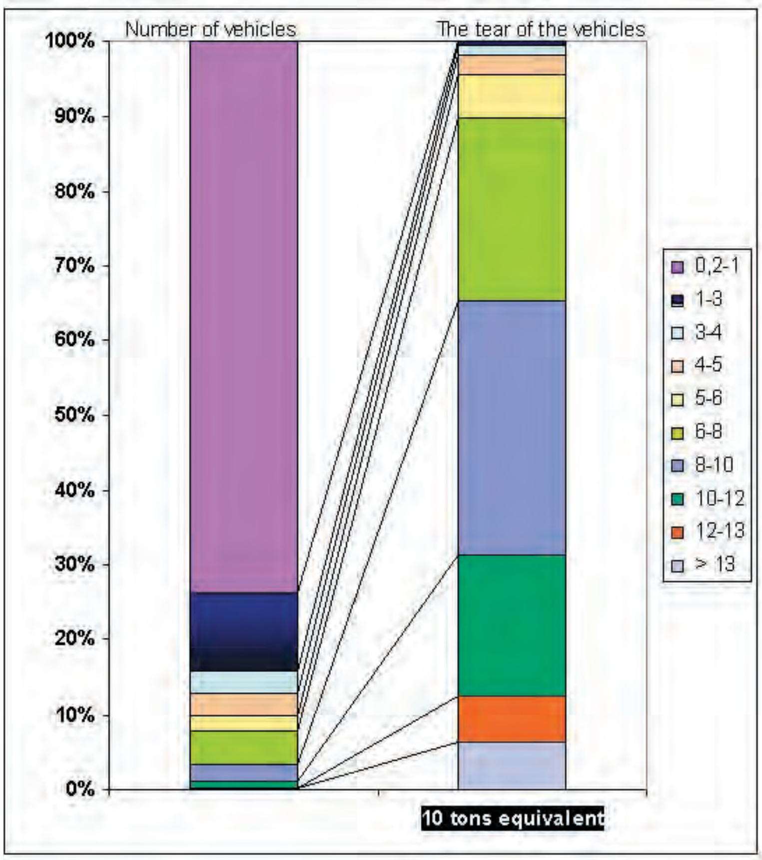
Each lane was built by all kinds of construction used. By this experiment it was possible to see how each of them was affected by a certain type of traffic.

By the first larger reporting in 1930, the results showed that the horse vehicles wore disproportionately much on certain road surfaces. It was directly indicated that horse vehicles probably tore more than many light horse carriages. The same conclusion was not made for the motor vehicles for some unknown reasons.

The experimental road was established in 1926, and information was collected until it was closed down in 1939. Both before and after, there have been traffic censuses recording how many vehicles – and thus how much weight – a road has been loaded with over a period. In contrast, experiments like the one in which the traffic was divided cost enormous sums. The Danish experiment was actually a rather brilliant solution to have results with few means.

In defiance of efforts were made to obtain information about the traffic he interpretation of the collected information could give very wrong results. This was the case in 1939, when a report from the Committee of Roads at the Danish Road Laboratory stated that trucks did not even tear as much on the roads as twice the traffic from a private car. Even though a truck at that time only had a total weight of 3,6 tons, the result was – with the knowledge of today – very far from the reality.

Experiments under more controlled conditions were necessary, and I will mention some of the most important from the USA, which had a big influence not only on the American conditions but also the whole world. The problems with the tearing of the motorised vehicles were the same all over the



The figure shows how different types of vehicles are tearing on roads. In the left row is shown the numbers of the different vehicles distributed after their total weight. In the row to the right is calculated the tear on the roads. As is seen, the small private cars do not have a measurable tear; on the other hand, the few heavy trucks are the "bad guys" through their road destroying (the data are from a road census in 1973).
After the scientific knowledge had been expanded since the 1950's it became possible to calculate such figures.

world. Therefore, the responsible people collaborated at an early stage to exchange information. As early as 1908, the L'association internationale Permanente des Congres de la Route formed in Paris, and since then the congress has been the meeting point with some years intervals.

The first large experiment with controlled traffic in full scale was carried out in the USA in 1950. It was called "Road Test I-MD" and was made by a cooperation of road administrations, the American Association of State Highway Officials (AASHO). A vehicle with two axels and one with three axels drove on an existing concrete surface over a long time period. From this experiment a very clear understanding was gained: that a vehicle would tear much less if the weight were divided on more axels.

In 1953-1954, another consortium of road administrations, the Western Association of State Highway Officials (WASHO), extended the experiment with the same results.

The most extensive experiment – and thereby the most important – was again made by AASHO. Over a period of two years (1958-1960) the vehicles were running almost 19 hours a day with 10 different combinations of vehicles six to seven days a week. All in all, there were six test roads each with many different kinds of surfaces and with small bridges.

The aim was to find the relationship between the numbers of loads with a known weight and the combination of axels on different covers and thickness of the bases.

The result was that a double axel could not carry double the weight of a single axel but rather only 1,8 times. An enlargement of the weight of a truck from 8 to 10 tons shortened the lifetime of a road surface by 58 %.

The accumulated times heavy axel passages

Parallel with this experiment, theories were developed in other areas of the road technology. Here only a few will be mentioned.

Measuring the capacity of the underground to consolidate a given road surface proved to be important. In California the so-called CBR-method (California Bearing Ratio) was developed, which in principle said that with a larger sinking of a piece of earth under a vertical influence, the lesser was the bearing ratio. The results were published in 1928, but the theory was first used after 1942 to a greater extent. Hereafter it was the number-one method for many years.

During the Second World War the belligerent countries lacked a method for dimensioning roads for heavy traffic, especially for fortification of airfields. Therefore, many results appeared after the war for civil use. Burmister published in 1943 a method for two- and three-layer covers on a circular area. This method was extended by Hank in 1948. According to this, the influence became an unvarying effect on a circular area. Hank published some tables with his results. This kind of table was important in this business, while the users from a few parameters – for instance, the stipulated coming traffic – could read the recommended thickness of the different covers.

The importance of the road foundation for durability began to be an important question, too. Hereby, the categorisation of

Surface on Danish highways 1934

	km	percentage
pavement	8	0,1
sett paving	706	9,2
concrete	25	0,3
asphalt pavement	185	2,4
tar pavement	105	1,4
coated macadam	1793	23,4
surface coated	3814	49,7
macadam	811	10,6
gravel	205	2,7
total	7652	99,8

The table shows the best ways in Denmark. Still most of the roads were not suited to truck or bus traffic. Only the first five types of surface could - perhapes - handle heavy vehicles. At that time less than 14 %

the soil according to its type began. The method from Proctor concerning the control of the compression of soil from 1933 came into use during the war and was in use for a long time.

Those and other theoretical and practical studies resulted in some practical tools, so the American Asphalt Institute published the book *Thickness Design* with curves over traffic and its weight compared to the CBR-number of the base. This material was built on the assumption that the roads had to be dimensioned to a rising traffic of 80 % over 20 years.

The other widely used resource was a publication from Shell (a large producer of asphalt), “Shell 1963 design chart for flexible pavements.” Here the CBR-number was similarly determined and the total number of axels counted in equivalent 10-tons axels calculated over the concerned road’s lifetime – here it was only seen on the heavy traffic— neither the personal vehicles nor the vans had any measurable influence on the lifespan of a road.

This target for the traffic pavement “the accumulated times heavy axel passages” became rather important. The theory was developed in the 1960s and was used by the road authorities through the publication from Shell. The reason, according the theory, was that every time a heavy axel passed through a piece of road, the pavement was influenced, and this finally resulted in a stress fracture like the way a wire was broken by a certain number of bendings. A road had therefore to be dimensioned at least as strongly so that in its lifetime just exactly could bear the weight.

The equivalent 10-ton axels, Æ10, became a measure for N, the number of 10-tons axle load that were compared to the actual accumulated. The actual weight on an axle can be inserted into a formula, and it is possible to calculate the influence. The damage of the pavement is changed with the fourth square of the axle load. For example, if we had to compare a truck with an axle load of 6 tons related to a rear axle of 0,6 tons, the truck has the same destructive power as that of 10.000 passenger cars; accordingly, a truck of 12 tons’ weight has an effect like 160.000 passenger cars!

For instance, the theory is not very exact because a compensation had to be made for a long list of conditions. One of them would be a truck with a so-called super single tire instead of a traditional twin tire that would give an even larger pressure.

Since the 1960s, a continuous evolution has occurred. Among the new methods the EDP has given whole new possibilities to calculate relationships between many different factors; however, the principal understanding of the pavement was shaped and resulted in a drastic improvement of the following road building.

The history of the pavement technology

When cars were accepted and the roads had to be constructed according to their needs, new pavements had to be developed. One of those, sett paving, was already developed. It was a new kind of pavement but now with rough-hewn stones that could better interlock with each other and thereby could give a steady road surface that created less noise and inconvenience. Moreover, it was very wear-proof, so it could keep for many years before the stones were worn down. If the foundation was in good condition, it could bear rather heavy vehicles. It had, though, a single but rather essential drawback: it was expensive. Therefore, it was mainly used in towns and on roads with much traffic.

The most common treatment after the cars began to raise dust was a simple sprinkling of the road with asphalt or tar. Soon came emulsions, where the binding material was soluted in water. Over this came a thin layer of small stones. This type was fine for passenger cars, but it could not handle traffic from heavy vehicles.

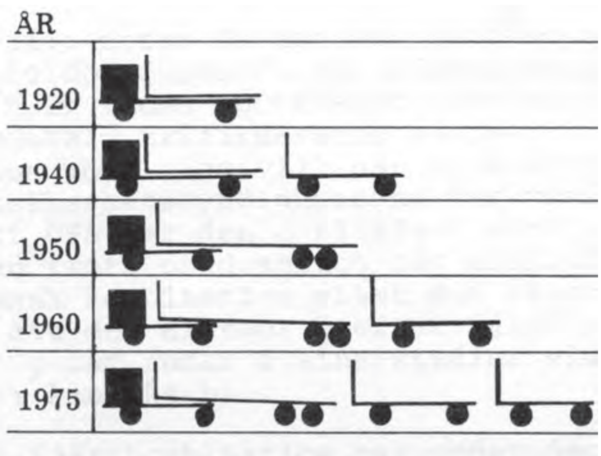
Concrete was a material that was used very much in countries like Germany and the USA. In Denmark the method was not very widespread, as only a small percentage of the roads were built with this material. It had some drawbacks – for instance, it took a long time for a road to be ready after construction or a repair. Made properly, it could handle even very heavy vehicles.

Most of the Danish roads were built by a combination of a soft binder together with stone and gravel. The binder was tar that came as a waste product from the gasworks or asphalt that from the middle of the 1950’s became the dominated binder. This material existed in numberless combinations of types of asphalt, sand, filler, and stones.

The next great progress in the development of the technology happened late in the 1950s, when much more attention was given to the condition of the soil. New methods for geological investigations meant that the ground for the roads was taken into consideration. Together with new scientific theories, better construction could be performed. For instance, it was started to stabilise the soil in different ways with rolling and vibration tools and after adding concrete or hydraulic lime.

The tools for road building have had a similar evolution. The mechanisation happened seriously after the second World War, and an almost industrial building of roads happened since the 1960’s – often parallel with a reorganisation where allocations of contracts and liberalisation gave better possibilities to organise the road building (and, for instance, the maintenance, too) more rationally.

In the last years of the millennium more asphalt mixes were developed. Where several layers already were being used in the 1960s, in the 1970s asphalt came in depths down



Silhouettes of different combinations of trailers and wheels. This figure only shows a few of the combinations. The figure is from Sweden where it is allowed to have two or more trailors on a truck. This is not allowed in Denmark.

Types of heavy trucks, 1969

2 axles	42 %
2 axles with 2 axles trailer	33 %
3 axles with 2 axles trailer	7 %
2 axles with 1 axel trailer	6 %
3 axles	4 %
2 axles with 3 axles trailer	4 %

to 37 cm or more. This was not only a better way of road building through the materials but a better way of calculating the building, too. As will be explained later, the weight limits for the vehicles were raised, and a more extensive load was allowed. While the foundation layers were getting better, the heavy trucks gave a larger tear that resulted in wheel tracks. Especially when the maximum allowed tire pressure was raised so super single tires could be used, serious problems appeared. Once more, it was necessary to develop new technologies for making softer bitumen so the surface layer could be flexible and straight after hard influence from a heavy vehicle.

In the middle of the 1970s came changes in the construction caused by the rising concern for environmental problems. Used pavement would no longer be thrown away but was reused as road materials. At the same time, the shift from oil to coal in the readjustment under the oil crisis meant that there was a lot of fly dust that could/should be used for roads. Accordingly, slag from steel production was used, too.

Modification through polymer in the bitumen became a new product at the end of the 1980s, and once more new and better construction could be performed.

The road-building economy

Roads have their own unique economy. Investments were longsighted, so there had to be some very longsighted decisions. It was in many ways like forestry and railroad building, though not with such long perspectives.

For example, in 1944 – when cars had been around for more than 40 years – a large part of the roads were still unsuited for use by cars and at least not for heavy vehicles. In the large cities the roads were of a rather fine standard; of the almost 3.000 km of road, only a few kilometres were unusable for motor vehicles. In contrast, more than one-third of the roads were not for heavy vehicles.

With a little more than 8.000 km, the highways were rather suitable for the light vehicles. Only a few kilometres had no cover. For heavy vehicles the nearly 5.500 km had a surface that not was the best.

Worse were the roads in the smaller communities. Of the 44.00 km secondary roads, 23.000 were simple soil or sand roads and therefore unusable for car driving at all. Only a small percentage of all secondary roads could be used for heavy vehicles.

In all, after a generation of car driving the condition of the Danish roads was still what, for over half of the roads, was unsuited to car driving.

Since 192x, the small communities had received shares of the tax income from motor driving, but the development went very slowly.

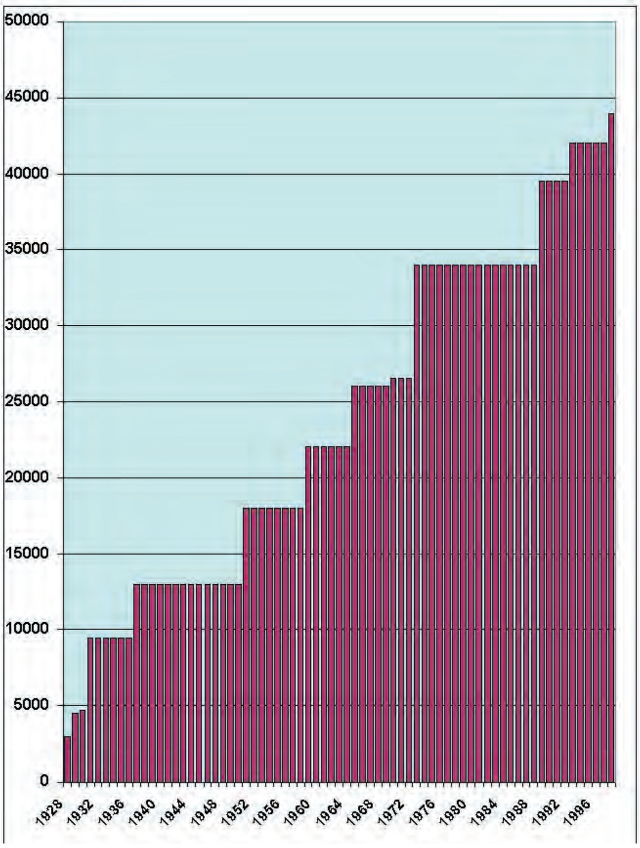
To illustrate the problem for the road administration, the development from one of the 24 Danish counties, Ringkøbing County, can be described. This county was atypical in the sense that the direction solely used the sett paving for the building of new road pavement, where the other counties normally only used it for the most trafficked roads in town areas. Of these counties' 459 km of road in 1944, 255 km were coated with sett paving. Almost all of the rest were gravel roads.

Initially the direction stood in a classical process of decision: should the means be spread on investments in middle-quality solutions on many roads and have the risk that those roads soon had to be remade in a costly process, leaving no more money for construction of new roads? Or should they build the roads first-class from the beginning on a few kilometres of road a year and then wait for the rest of the roads?

The second solution was chosen. The roads with sett paving were slowly made, and the wear-proof cover was gradually put on more and more roads.

The opinion of many users of the roads in the county was that the process went too slowly. They thought that there had to be solutions for the bad roads too, and a heavy public protest against this priority resulted.

The priority proved to be wrong. At least when the weight for the vehicles was raised in the 1950's, the roads were not good enough. The stones themselves were fine, but the ground underneath was not. Therefore, the trucks sank through the roads, which had to be remade with great expense as a consequence.



The figure shows the load for the heaviest truck delivered from the Volvo factories. From each model is taken the heaviest combination of truck and trailer. The data behind the figure is not so accurate that it is possible to know the year of the heaviest truck; generally the year of the first appearance of a model is taken. As seen the capacity is mooving upwards rather stable.
Volvo is a typical manifacturer of heavy trucks. The general picture will be rather similar.

When the roads were the number-one infrastructure in the society, it should come as no surprise that an increasing lobby was made for raising the allowed weight of the truck and load. Around 1980, a passenger car drove 15.000 km a year (German numbers), an ordinary truck 24.000 km, a bus 50.000 km, while an articulated lorry drove so much as 66.000 km.

At the same time, the Danish carriers added that the axle load should go up to 10 tons. It would provide a yearly savings of 200 mill. Kr. Uncertain estimates showed that it would cost 1-1½ billion to improve the roads.

The development of truck technology
As mentioned, it was possible to build large trucks very early in motor history. There was, moreover, a development of all of the components on a truck that together have given the effective means of transportation. Some of the springs in the technology has been more epoch-making than others. In the following some of these will be mentioned. Some years will be mentioned, too, but all had to be regarded as approximate years. Many of the technologies were developed earlier, but the given years were the time when the products actually were ready for the customers.

The engine has always been the heart of the vehicle. Users have wished for more power and torque, together with reasonable fuel efficiency. Slowly the output crawled up from a few HP to the contemporary motors with several hundred.

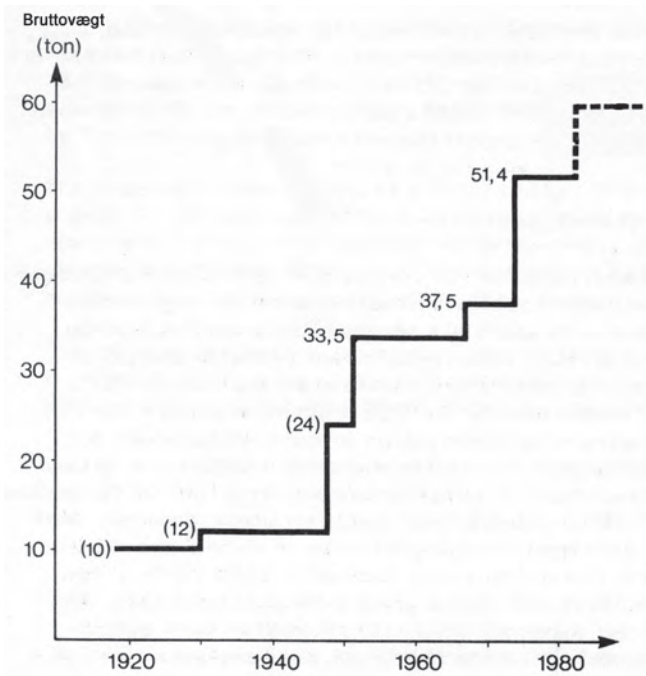
The diesel engine was one of the larger innovations with a stable and rather more economical motor than a similar petrol engine. We are talking about heavy vehicles for which fuel efficiency was essential. Though this engine was made for the first time as early as the 1930s, it was in the 1950s

The economy of truck driving
It is evident that a larger load on a truck – other things being equal – would give a better economy than with a lesser freight. Though a larger truck would cost a little more than a smaller one, there are more of the regular expenses like for the driver and so on, there fore could the expenses be divided and paid by the larger load.

The problem was perhaps not that big in the beginning of the motor era, when the truck only handled local traffic. It carried small loads for the local grocer, for instance.

For still some years transportation over longer distances was most convenient by railways. A traffic census in 1929 showed the transportation in the country: The roads had one-fourth of the transportation, and the railways three-fourths.

In spite of state subsidy and rather restrictive rules for transport with trucks, the share of transported freight on the railroads felt steady. The trucks were flexible, faster, and highly precise, and they could drive often. Already in 1952 trucks were obtained to drive more than half of the freight in the country, and 15 years later this figure was 80%. Trucks were important for most of the transportation. The larger the load could be and the faster the vehicle could drive, the better it was.



Through time the maximal weight for vehicles have been raising steadly. This figure shows the Swedish development but for most other countries it gives the same picture.

With this road sign general rules could be underruled if a part of a road or a bridge was too weak for heavy transportation.

that it first dominated over the petrol engine (the situation for the buses).

In that time there came many new innovations with and around the engine. Around 1950, direct injection gave the engine a lift, and the introduction of the turbo-charger in 1955 gave the engine still more power. In the beginning of the 1980s, the inter-cooler came, and with microelectronics in the 1990s came many new regulation methods: for instance, electronic injection control.

The automatic gearbox came as early than the 1930's, though it was a long time before most of the vehicles had this technology. Ten years later the synchronized gearbox came, giving drivers rather more easy work. After ten more years the servomechanism came, and then the job of driving a heavy vehicle was not only for strong people.

As we will see later on, the axles and tires underwent an important development.

The brakes were essential because they were the basis for allowing a higher speed. The use of compressed air from the end of the 1920s was an important innovation. Compressed air could also be used for many other functions such as activation of the dump body or a crane.

Suspension has had it own development, too, not least from the 1960s, when the air cushion appeared.

A part of the technology is the ways of arranging the vehicle. There came the so-called "bulldog" type since the 1930s, with the engine lying under the seat of the driver to give better manoeuvring. This construction could create problems when the engine was repaired, but this problem was solved when the cab could be tipped.

The traditional vehicle with four wheels and a platform soon received an extension with an extra trailer. The combination of trailer and wheels has been varied in many ways. The articulated trailer became popular, as the vehicle itself could be disconnected so the driver would not have to wait for the on- or offloading.

Much has happened with the technology. Shortly it has given a larger speed and less own weight related to the net weight of the total weight that has been raised steadily through time.

The vehicles in a country are not optimal all of the time. In a period of their lifetime, perhaps 15 years, there had to be vehicles with almost 15-year-old technology. Many carriers do not even want to have larger trucks if they are only driving local transportation.

For example, all the vehicles in Denmark in 1981 were spread on a long list of weight classes. Almost half of the less than 80.000 trucks had a total weight of less than 4 tons in total. From this there were sliding conversions to vehicles of 16 tons. Trucks with more than two axles mainly had a weight over 20 tons in total.

Restrictions for vehicles

There was – and is – a long list of restrictions against the use of vehicles on public roads. The following will show a list of those. They are described in small chapters ordered after themes.

The history of restrictions is rather confusing. On one side there are many possibilities for dispensations to drive with heavier or faster vehicles; on the other side there can be many additional restrictions: for instance, caused by local situations.

Total weight

Restrictions for the new motor vehicles soon came, and weight limitation was among the first. A maximum weight for a vehicle was established. In the first years there was uncertainty about the weight, but the total weight became the starting point for the restrictions. In 1927, the tax system for vehicles was changed. The vehicle excise duty was made so that it was rising, particularly for the largest trucks. Up to 1.200 kg, 13 kr had to be paid per 100 kg of the weight of the vehicle; for weight over 1.200 kg,16 kr had to be paid; and similarly, 18 kr. and 20 kr. for weights over 1.500 kg and 2.000 kg, respectively, had to be paid.

Gradually it was realised that the tear on the roads was dependent on the weight of the pressure from the axle and probably not the total weight. On the other hand, there had to be a maximum weight in respect to bridges. New rules were later introduced in connection with the fact that large parts of the road grid have obtained a new higher standard. For instance, in 1939, all bridges could handle driving with a 50-ton truck.

For that matter, there was uncertainty for a long time about what bridges could handle, especially when Denmark became a member of NATO in 1949 and the military more or less was forced to acquire some special heavy British tanks.

Bridges built after 1965 were supposed to be able to handle a weight of 100 tons because the rules at that time stated that new bridges had to handle this weight. In 1974, the weight limit was raised a little; now vehicles of 78 and 38 tons' weight should be able to drive on the bridge at the same time. In 2002, the weight was raised further to 150 tons for one vehicle, or if there were three vehicles at the same time, the bridge should handle 60-ton, 40-ton, and 20-ton vehicles.

Special transport can be made through certain approved roads. In the increasing societal need for this kind of transportation organisational systems are build to facilitate the transport.

Still, a general problem with the rules about weight arose: The rules were not followed. Trucks have often been overloaded, and as mentioned, it is the heaviest vehicles that tear exponentially the most on the roads. In 1967, the Danish road administration placed its first weight that could measure the pressure of axles. It showed that a rather large number of trucks were driving with overload.

In 1977, the maximum load was raised to 44 tons, and today the maximum is 46 tons.

Axle pressure

After realising that it was the high axle pressure that was to blame for the destruction of roads, rules for maximum axle pressure were instituted. In 1927, the limit was set to 6 tons. This limit was kept until 1947, when it became permissible to drive with 7 tons on highways. In 1955, this rule became the general rule for all roads.

When investigations had shown that a vehicle with twin wheels distributed pressure better than a single axle, the trucks were allowed to drive with a higher weight. In 1955, twin tires were introduced in the rules, and now pressure from an axle with those installed could be 8 tons. In 1977, this limit was raised to 10 tons, and in 19xx it was raised to 11½ tons.

For instance, there were many special rules depending on the number of axles, pressure from bogies, and so on. In 1977, a two-axled bogie was allowed to carry up to 16 tons, and a three-axled 22 tons (if the mutual distance between the axles was 1 m or more). When every country had their own rules of this complicated kind, whole books had to be published for drivers that wanted to drive between the European countries.

Moreover, many of the existing fleet of trucks could be rebuilt from carrying a 10-ton load to 11½ tons. When the new rule was introduced, almost 90 % were assumed to have their pressure increased.

Wheels

For the first years of the 1900s, large trucks had to drive on massive or half-massive tires. Even the heaviest pneumatic tires in 1914 could not be put on vehicles for more than 2 tons. Those trucks had to use massive tires or even rings of steel. This meant a large dead weight for the vehicle, so its own weight exceeded the payload. The speed was reduced, too, because even the best massive tires could not handle a speed over 40 kmph. Therefore, the trucks could not drive outside the best roads in the towns. The secondary roads could not manage the bumps from the heavy traffic that in a short time would have destroyed the roads.

One of the really large technological advantages was a pneumatic tire that could handle heavy trucks (and similarly buses). In 1919, the first of these tires for heavy trucks that could handle a load of up to 1.100 kg per tire appeared. With a pressure of 7 atmospheric overpressure, these rings could be used on trucks up to 3 tons. The durability of these tires was, however, only for driving 10.000 km, where a tire on an ordinary car could drive 17.000 km. The load was raised first to 5 tons and later to 7 tons.

In 1927, special high taxes were introduced, 25 % for approved half-massive tires and 50 % for massive and non-approved half-massive tires. A calculation from the Vejlaboratoriet in 1931 confirmed the theories about their wear and tear from tires. In the period 1926-1930, there was a wear and tear of 3,6 cm2 per million tons by use of pneumatic tires, while it was 55 cm2 for massive tires and 200 for those of steel.

In 1928, a new improvement came. Now it succeeded in constructing tires with a low pressure even for heavy vehicles. Those new tires were known as balloon tires, and they could handle the weight with only a pressure of 4 atmospheric overpressure. The improvement was as big as when the first pneumatic tires arrived. It was tried to increase the circumference of the ring to reduce the internal pressure, but with the tires for the heavy trucks a limit for that time was achieved.

In 1934, it was possible to build pneumatic tires for cars with over 10 tons' axle pressure and a 25-ton payload, where it is now possible with a vehicle of only 13 tons own weight. Those heavy balloon tires could now drive more that 100.000 km. It was a great thing because previously tires could create costs of more than 30 % of the total expenses.

At this time the road engineers had discovered that the tear on the roads had another composition than previous stated. The tear on the surface itself was dependent on the weight/pressure per cm2. The pressure for all vehicles with balloon tires was now not greater than the allowed because the balloon tire caused the pressure to be independent of the weight and only of the air pressure. The real road destroyers were the vehicles with massive tires, and they were disappearing very quickly.

In contrast, it was discovered that destruction happened in the depth of the road. With this new tire it was possible to spread the weight on several axles without putting a higher maximum pressure on the road.

Local rules

For the present we have heard about the general rules. To a great extent there have been many more rules for specific roads. The rules could give restrictions, but they could be extending too.

In the first decade it was indeed forbidden to drive on the secondary roads, but the local authorities could still give

National rules, maximal total weight 1934

	2 axles	3 axles	train of carriages
Tyskland	13	18,5	
Frankrig	15	15	
England	12	19,3	22,35
Italien	10	12	
Danmark	8	8	8

At the Road Congress in Münich 1934 the rules between different countries were compaired. It showed big differences - here some examples. As seen the Danish rules were very bad compaired to the others.

National rules, maximal width 1949

Norway, Switzerland	**2,20**
Britain	**2,29**
Denmark	**2,30**
Austria	**2,35**
Sweden, Holland	**2,40**
Portugal	**2,45**
Belgium, France, Italy	**2,50**

Even there were widespread possibilities for dispensations the table shows the problems the body makers and haulage contractors had for international transportation. A bus or truck bild for the the roads in France, for instance, could not drive in Norway or many other countries.

dispensations in some situations. Later, according the general rules, it became permissable to drive heavy vehicles, but these local authorities could then forbid driving on their roads with weights over 1.450 kg. This limitation was raised to 1.600 kg in 1927; there was, though, an exception for passenger cars with fewer than seven passengers.

The local county could protect bridges of a special light construction against rather heavy or broad traffic.

Road signs easily marked prohibition against the heavy vehicles.

In Norway there has been a more systematic way of protecting roads. For instance, protection against long vehicles could be done through categorising the roads in three different types: 18, 15, and 12,4 roads (1983). At the same time, these numbers gave the maximum length of a vehicle with a trailer.

Reversed, driving could be allowed even with very heavy vehicles. It could be realised if the vehicles follow special roads. Special rules were established for export drivers that obtained rights to drive with loads in foreign countries. They could have a greater total weight and axle pressure than the general rules gave. They then had to follow special durable roads.

There could be a need to also have transports with special heavy goods like many of the new technical units. For instance, there could have been a need to transport a transformer substation to power stations in the middle of the 1950s. Transports of special long vehicles came with the production of windmills in the present time.

Ordinarily the police and the authorities together could give permission for these special transports. When their numbers rose, these rules were formalized in 1977. A "blue road grid" was created where the heavy trucks were allowed to drive. Actually, it became a rather large part of the Danish highways – the length rose to 6.800 km. To protect bridges and partly the roads, too, these transports were not allowed to move faster than 40 km per hour. The blue road grid was marked on maps where each single road or bridge had its maximum load written.

Year of time

A rather special phenomenon had to be taken into consideration concerning restrictions, namely the prohibition against the driving of heavy vehicles at certain times of the year. It is the so-called melting damage, which happens during the break of the frost.

The winters were hard on the roads, and strong winters could destroy large parts of the Danish roads. Actually, it is not the winter but rather when the winter stops that the damage occurs. The reason is ice crystals that form where water via a capillary is raised from the underground. Earthlike clay has the capability to suck water up, and the result is that not only heavy vehicles but even light ones can destroy a road where those crystals are thawed and the water is not drained away. The road becomes almost kneaded in pieces.

There were some bad winters in 1912, 1917, and 1924, when many roads were destroyed. At that time it was only possible to place sprigs of spruce where the holes should be protected against traffic so the wheels did not dig further into them.

The most effective way to stop the destruction was to stop the driving of the heavy vehicles at all. It to some extent allowed the authorities to forbid driving. For the buses there were rules that they could be stopped, but for trucks the rules did not give the same possibilities. One of the counties wanted in 1923/24 to stop the driving of trucks over 1.450 kg, but this was not allowed by the Ministry of Justice. Instead, the road authorities had to request the drivers to stop driving.

After the weight limits were raised in the 1950s, there was some large damage over a period of years.

Still, today the roads are very weak during the break of the frost. It is, though, the fewest places that ordinary vehicles gives problems but there is problems for special heavy transport and therefore there are still some restrictions.

Speed

In Denmark, as in all other countries, restrictions have been made against high speed through maximum limits.

These limitations have been made not as much for the respect of the roads but more to prevent accidents, though the former speed limits could to some extent be suited to protect the drivers against bad roads where the profile not was made for fast driving.

In the 1980s the limits for trucks were 60 km/h in towns, 80 km/h outside, and on the motor roads up to 100 km/h.

Length, width, and height

The haulage contractors have naturally wanted to drive trucks as large as possible so there could be a better place for the load to be packed. On the other hand, the dimension of the vehicles had to be restricted, too: Rather high vehicles would hurt the bridges and viaducts, broad vehicles would hinder oncoming traffic to pass each other, and rather long vehicles could not swing in crossroads.

Today the vehicles are allowed to be 18,75 m long, and "special vehicles" are allowed to be up to 50 m. The business world has more wishes for longer vehicles. It had to be mentioned that in some countries like Sweden is it permissible to drive with more than one trailer. Here the authorities will adapt the need for transportation in the large and less settled country with much transport to the big export harbours.

International cooperation and standards

In 1908, the road authorities in a large part of the world collaborated to find solutions for the new century's big problem: to find suitable pavement for motor transportation. It became the start of a world congress with increasing participation in the meetings arranged with some years' intervals.

One of the largest and most important congresses was carried out in Munich in 1934. Previously the national delegations had discussed the building of roads, but this time the congress also had some discussions about the rules that regulated the use of the roads.

The report to the congress showed big differences between the countries. On several fields Denmark was behind the development. At that time the country still had the rigid rule that a truck could only have a weight of 8 tons in all – independent of how many axles the weight was distributed on. Most of the countries around Denmark had introduced rules with differentiation after the numbers of axles. In Great Britain, for instance, a truck could have a total weight of more than 22 tons.

In many countries the maximum speed was very much higher than in Denmark. For trucks under 3 tons the speed limit was free in several countries, and in Italy the speed was free for vehicles up to 6½ tons.

ECE's rules 1949

After World War II it became obvious that international transportation would continue and that there would be a rise in it, too. Small attempts early on to international connections would continue to a greater extent.

It was therefore natural that the United Nations would work toward an international standard for driving on roads (a similar effort to make an international signposting has had great success). At a congress in Geneva in 1949, there were negotiations on proposals to international standards after a registration of the present rules. The suggested rules included mainly the broadness and the weight of the vehicles. In terms of broadness, Denmark was at the bottom with its 2,3 m width out of the 12 countries. Only Norway and Switzerland had a smaller width of 2,2 m. A bus from Norway could drive all over Europe, while a bus 2½ m wide from France could only drive in Italy, Belgium, and Poland without dispensations. The meeting recommended that there should be work toward a European standard of 2,45 m for the broadness of a road.

Similarly, the maximum axle pressure in Denmark of 6 tons was on the lower end, too. Only Norway and Sweden had lower pressure, but there dispensations could be given. Some of the countries even had roads for up to 16 tons. The meeting recommended a European standard of 8 tons.

EU rules

Within the EU work has begun for equal European standards. In 1984, a directive was decided on for the load and dimensions of heavy transportation vehicles. The rules were implemented two years later. The largest barrier was the decision taken that the member states from 1992 had to allow an axle pressure of 11½ tons.

There were requests for higher levels, and work was begun to allow very heavy vehicles if they had some special road-friendly constructions. It was known that pneumatic suspension was more gentle to the roads, and it should be investigated whether there were other suitable suspension systems.

Conclusion

There has been a continuous "balance of terror" between the haulage contractors with their requests for larger vehicles on one side and the road administration that wanted to protect the roads on the other side. The politicians always had to promote the development in such a way that they could follow the wishes of the businesses, but on the other side they could not be pressed to give rules that were too liberal, with the consequence that they had to approve large grants for increasing the pavement on the existing roads.

There have been periods when the haulage contractors and the industry, to a large extent, have had their claims accepted. This was the case in the 1960s after some more "realistic" methods to calculate roads were developed. At the same time, this gave a knowledge of new principles of construction, so there was a period when the roads complied to the wishes of the haulage contractors at that time.

In more than 70 years there has been work toward decisions for international standards. Many suggestions have – with some delays – succeeded. Denmark has on most items been a member of the group of countries with road standards under the average and accordingly with "foot-dragging" in its policy.

The carrying capacity of roads and bridges has been determined from varying historical, geographical, economic, scientific, and organisational factors. It is supposed that many of these factors will exist in the future. The limitations for weight, length, and so on will continue to climb up, though it is difficult to imagine that the complicated patterns will give a total synchronized European development.

Note

The investigation's starting point is the ongoing research project, "Danish overland routes 1868 – 2006" (working title) at the Danish Road and Bridge Museum.

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Among his works about traffic and transportation are:

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